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REPORT

The performance of a satellite link using the BBC Transportable Earth Station with EBU – leased capacity in the European Communication Satellite system

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THE BRITISH BROADCASTING CORPORATION

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Summary

The Report describes a series of tests on a satellite link established between the BBC Transportable Satellite Earth Station and a BTI fixed earth station using an EBU-leased transponder on the ECS 2 satellite. The transmitted power was limited to comply with new regulations imposed by the satellite operator, but the results indicate that a high-quality television link can still be established over a potential coverage area which includes most of Europe. Also, under these conditions an adequate fading margin is obtained for all but 1.75 hours per year.

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1. Introduction

The BBC has an arrangement, via the EBU and BTI, to lease capacity in the European Communication Satellite (ECS) system, for Eurovision links between fixed earth stations operated by European PTTs, and for outside broadcast links using the BBC Transportable Satellite Earth Station (TES). This capacity comprises a pair of satellite transponders on ECS 2 (each provided with a redundant spare), and transmission and reception facilities at the BTI large, fixed earth station at Madley, near Hereford. At the time of writing, the name of this satellite is being changed to Eutelsat 1 – F2; for "flight 2".

The TES[1] was designed to operate initially with the Orbital Test Satellite (OTS), and then, following the commencement of the EBU lease, with the ECS system. Around the beginning of 1985 the facilities at Madley for BBC/EBU operations were commissioned, but Interim Eutelsat, the administration which operates the satellite, had already imposed a new restriction on the maximum power that could be transmitted by the TES in order to protect other ECS and Intelsat satellites from interference. This restriction is directly related to the sidelobe levels in the radiation pattern of the dish antenna fitted to the TES, and means that for the present time the on-axis equivalent isotropic radiated power (e.i.r.p.) is limited to 72 dBW. After 1987 the restriction is likely to be made more stringent.

Initial tests had been performed in 1984 using the TES with ECS 1 and the pre-operational Madley earth station, but the results were not very satisfactory. Therefore it was planned to repeat these tests as soon as the higher-specification ECS 2, and the fully-operational Madley earth station were available.

In March 1985 the TES was linked to the Madley-4 earth station using one of the EBU-leased transponders for a series of transmission tests using PAL television signals with sound-in-syncs (SIS). The aims of the tests were to measure the performance of the satellite link with the new e.i.r.p. restriction applied to the TES, to observe the variation of link performance with up-link (transmitted) power, and to determine the margin against up-link fading with these conditions. From these results the potential coverage area can be derived.

2. Test facilities

The TES was located at the BBC Television Outside Broadcast base at Acton for the duration of the tests and was used as the up-link transmitter; at Madley only the reception facilities were used. Transmission and reception facilities were also provided at the BTI Goonhilly earth station, in Cornwall, to facilitate calibration of the e.i.r.p. and polarisation of the TES.

Transponder 9 of ECS 2 was used for all of the tests. The transponder can be remotely controlled to give 3 dB more gain than usual which would have been of great interest but, as the facility is not available within the terms of the EBU lease, the tests were performed with normal transponder gain.

The Madley earth station was equipped with instruments for objective measurements of i.f. carrier-to-noise ratio (C/N), demodulated video signal-to-noise ratio (S/N) and video distortion parameters. Facilities were provided for the "standard" operating conditions of 36 MHz bandwidth/25 MHz deviation* and also for the Eutelsat "half transponder" conditions of 30 MHz bandwidth/19 MHz deviation*. These latter conditions can be used to relay two television signals through one 80 MHz bandwidth transponder, but in this case our interest was only in the C/N improvement afforded by the smaller f.m. bandwidth.

SIS decoders, and audio and video monitors were provided at the receiving earth station for informal subjective assessment of the received signal quality and to indicate the onset of threshold effects, but a terrestrial link was made available to relay the composite video/SIS signal back from Madley to the BBC London Switching Centre where more-formal subjective tests could be performed. A digital Slide File equipment[2] was located at Acton to provide suitable EBU test-slide material for subjective tests.

* These are maximum values of peak-to-peak f.m. deviation at a baseband frequency corresponding to the 0 dB point of the pre-emphasis characteristic (to CCIR Rec. 405-1).

3. Test programme

All of the tests were completed during one day, and there was sufficient time available for repetition of the most important C/N and S/N measurements.

3.1. Initial line-up

Initially, to fulfil the requirements of Interim Eutelsat, an abbreviated Initial Full Line-up procedure (IFLU) was conducted between the TES and Goonhilly. This comprised setting the polarisation angle of the TES antenna for minimum interference to the orthogonally polarised Transponder 3 and measurement of the resulting cross-polar isolation (XPI). This was carried out with Transponder 9 switched off.

Transponder 9 was then restored to normal operation and the reference 72 dBW, maximum e.i.r.p. was set at the TES by a power-balance method, with both the TES and Goonhilly transmitting simultaneously with reduced e.i.r.p.

3.2. Tests using "standard" operating conditions

At 72 dBW e.i.r.p. the received C/N, S/N and video distortion parameters were measured at the receiving earth station using "standard" operating conditions.

The C/N was measured by radiating a plain carrier from the TES, and by changing its frequency (by only 5 MHz) so that the received i.f. signal was offset in and out of the passband of a filter of known noise bandwidth. This method has the advantage that all components of the link are constantly loaded with a signal at the operating level, so components such as the a.g.c. amplifier in the receiver have no detrimental effect on the measurement.

Video noise was measured on "quiet line" 12 and video parameters were measured using full-field test waveforms.

The e.i.r.p. was then reduced in 1 dB steps and the C/N and S/N were measured at each step. This process was continued until severe threshold noise was apparent in the received signal.

The C/N and S/N measurements were repeated on two occasions, about two hours and eight hours later, in order to examine the diurnal variation of these parameters.

3.3. Tests using "half transponder" operating conditions

The TES and the receiving earth station were then set up for "half transponder" operation and the previous series of tests was repeated, including later, the two repetitions of the C/N and S/N measurements.

3.4. Subjective tests

A series of subjective tests was then conducted with two experienced viewers at the BBC London Switching Centre using picture material such as Test Card G and various standard EBU test-slides. In each test the e.i.r.p. was reduced progressively from 72 dBW to that which gave rise to threshold conditions. For these tests both "standard" and "half transponder" operating conditions were used, and a tone was transmitted on the SIS so the onset of SIS errors could be noted.

4. Results

The results obtained at Madley agreed very closely with expectations.

4.1. Initial line-up

The TES polarisation was set initially by nulling the locally received satellite beacon signal, and then with information from Goonhilly the XPI was maximised. The ultimate value was 37 dB, which is adequate for ECS operation (components of 35 dB are required for both the up- and down-link earth stations).

A calibration was established at the TES, corresponding to 72 dBW e.i.r.p., using a power meter coupled to the transmitter output.

4.2. Tests using "standard" operating conditions

The C/N, S/N and video distortion parameters were measured at 72 dBW e.i.r.p. The results are shown in Table 1. BBC Designs Department equipment was used for the video measurements.

The C/N and S/N values for the 1 dB steps of reducing e.i.r.p. are shown in the left-hand column of Table 2: a hyphen indicates that no measurement was made. S/N was measured with unified weighting as well as unweighted, but the difference between the two results was a

TABLE 1

Measurements at the receiving earth station for 72 dBW e.i.r.p. from the TES

Parameter	"Standard" operating conditions	"Half transponder" operating conditions
C/N	17.2 dB	17.8 dB
unweighted S/N	43.0 dB	40.5 dB
unified S/N	54.0 dB	51.0 dB
2T pulse K	0.8%	0.8%
pulse/bar K	0.8%	+0.3%
bar K	+1.4%	+1.7%
50 Hz K	−0.3%	no measurement
chrom./lum. gain inequality	−6.7%	−6.3%
chrom./lum. delay inequality	+26.0 ns	+18.0 ns
chrom./lum. crosstalk	+1.8%	+2.3%
diff. gain (black)	1.7%	2.4%
diff. gain (white)	2.0%	2.9%
diff. phase (black)	1.2°	1.0°
diff. phase (white)	1.9°	1.2°
lum. non-linearity (black)	0.8%	0.7%
lum. non-linearity (white)	1.0%	1.0%

constant 11 dB (within a ±0.5 dB tolerance for the resolution and accuracy of the measuring instrument), so only the unweighted value is shown.

The results of the repeated measurements of C/N and S/N are shown in the middle and right-hand columns of Table 2.

4.3. Tests using "half transponder" operating conditions

The measured values of C/N, S/N and video distortion parameters at 72 dBW e.i.r.p. are shown in Table 1 alongside the values for standard conditions. The initial C/N and S/N values for the 1 dB steps of reducing e.i.r.p. are shown in the left-hand column of Table 3, and the results of the repeated measurements are shown in the middle and right-hand columns.

4.4. Subjective tests

The results of these tests are presented in Table 4 for "standard" operating conditions, and in Table 5 for "half transponder" conditions. With 72 dBW e.i.r.p. there was no visible noise on the picture at Switching Centre, and no degradation to the SIS sound channel.

Fractional values between grades (such as 4.8) were awarded when there was a suspicion of an impairment, but it could not readily be identified.

5. Analysis of the results

The levels of video distortion measured at Madley were acceptable for both sets of operating conditions, and the r.f. performance of the link at 72 dBW e.i.r.p. was remarkably close to predictions. This is illustrated in the Appendix, where a link budget is presented for "standard" operating conditions (neglecting a.m./p.m. conversion). Because of the satellite output backoff, the link performance was not totally up-link dominated, although the noise contribution of the down-link was fairly small.

In an earlier series of tests using ECS 1 the full output power of the TES (76 dBW) had been used and the test results had displayed anomalies. One of the anomalies was an apparent discrepancy between predicted and measured values of the relationship between S/N and C/N at higher e.i.r.p. levels; it was speculated that this was caused by

TABLE 2

The effect of TES transmit power on C/N and S/N measurements using "standard" operating conditions (36 MHz bandwidth)

C/N

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	17.2	16.4	16.8	16.8	0.4
71	15.8	15.2	15.6	15.5	0.3
70	14.8	14.1	14.6	14.5	0.4
69	13.8	13.1	13.6	13.5	0.4
68	12.7	12.1	12.6	12.5	0.4
67	11.7	11.1	11.5	11.4	0.3
66	10.5	10.0	10.5	10.3	0.3
65	9.7	–	–	9.6	–

unweighted S/N (dB)

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	43.0	42.5	43.0	42.8	0.3
71	42.5	41.5	42.0	42.0	0.5
70	41.5	40.5	41.0	41.0	0.5
69	40.5	39.0	40.0	39.8	0.8
68	39.5	38.5	39.0	39.0	0.5
67	38.5	37.0	38.0	37.8	0.8
66	37.0	36.0	37.0	36.7	0.7
65	36.0	–	–	36.0	–

(S/N) – (C/N) (dB)

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	25.8	26.1	26.2	26.0	0.2
71	26.7	26.3	26.4	26.5	0.2
70	26.7	26.4	26.4	26.5	0.2
69	26.7	25.9	26.4	26.3	0.4
68	26.8	26.4	26.4	26.5	0.3
67	26.8	25.9	26.5	26.4	0.5
66	26.5	26.0	26.5	26.3	0.3
65	26.3	–	–	26.3	–

TABLE 3

The effect of TES transmit power on C/N and S/N measurements using "half transponder" conditions (30 MHz bandwidth)

C/N

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	17.8	17.1	17.5	17.5	0.3
71	16.3	16.0	16.4	16.1	0.2
70	15.2	14.9	15.2	15.1	0.1
69	–	13.9	14.3	14.1	0.2
68	–	13.0	13.2	13.1	0.1
67	–	11.9	12.3	12.1	0.2
66	–	10.9	11.2	11.1	0.2
65	–	9.9	–	9.9	–

unweighted S/N (dB)

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	40.5	40.0	17.5	40.5	0.5
71	39.0	39.0	39.5	39.2	0.3
70	38.0	38.0	38.5	38.2	0.3
69	–	37.0	37.5	37.3	0.3
68	–	36.0	36.5	36.3	0.3
67	–	35.0	35.5	35.3	0.3
66	–	34.0	34.5	34.3	0.3
65	–	33.0	–	33.0	–

(S/N) – (C/N) (dB)

e.i.r.p. (dBW)	measurement (dB)			mean value (dB)	spread (±dB)
	First	Second	Third		
72	22.7	22.9	23.5	23.0	0.5
71	22.7	23.0	23.1	22.9	0.2
70	22.8	23.1	23.3	23.1	0.2
69	–	23.1	23.2	23.2	0.1
68	–	23.0	23.3	23.2	0.2
67	–	23.1	23.2	23.2	0.1
66	–	23.1	23.3	23.2	0.1
65	–	23.1	–	23.1	–

TABLE 4

Subjective performance of the satellite link using "standard" operating conditions

Picture material	Uplink e.i.r.p. (dBW)	Picture quality	Sound quality	Comments
Test Card G	72	5	5	
	71	5	5	
	70	5	5	
	69	4.8	5	
	68	4	5	Noticeable background noise, occasional threshold spikes
	67	3	4	Clicks on sound
	66	3	2.5	
Formal Pond	72	5	5	
	69	5	5	
	68	5	4.5	Occasional threshold and clicks
	67	4	4	Definite threshold and clicks
	66	2.5	3	
Boy with Toys	72	5	5	
	68	4.5	4.5	Just perceptible threshold and clicks
	67	4.5	4	Definite threshold and clicks
	66	3	3	
100% colour bars	72	5	5	
	69	4.5	5	Occasional threshold spikes
	68	4	5	
	67	3	3.5	
	66	1.5	2	
75% colour bars	72	5	5	
	69	4.5	5	Better than 69 dBW with 100% bars
	68	4	4.5	Occasional clicks on sound
	67	3	3.5	
	66	1.5	1.5	
Young Couple	72	5	5	
	68	4.9	4	
	67	3.5	3	
	66	2.5	1.5	

TABLE 5

Subjective performance of the satellite link using "half transponder" operating conditions

Picture material	Uplink e.i.r.p. (dBW)	Picture quality	Sound quality	Comments
Test Card G	72	4.5	5	Just visible background noise
	68	4	5	Clearly visible background noise
	67	3.5	3.5	Threshold spikes
	66	3.4		
Young Couple	72	5	5	
	68	4.5	5	
	67	4		Visible background noise
	66	3.5		Threshold spikes
Formal Pond	66	3.8		
Boats	66	3.3		Threshold spikes more visible than with Formal pond

a.m./p.m. conversion in the satellite TWT amplifier which on that occasion was operated near to the input level giving maximum conversion. For the present series of tests this relationship is shown in Tables 1 and 2, for the steps of reducing e.i.r.p. and the two sets of operating conditions. The theoretical values, for a video bandwidth of 5 MHz and a pre-emphasis improvement of 2 dB, are 26.3 dB for "standard" operating conditions and 23.1 dB for "half transponder" conditions. The agreement is very good and implies that, as expected with some 12 dB input backoff, the satellite TWT was operating in a fairly linear region and a.m./p.m. conversion was at a very low level.

The mean values of C/N and S/N are plotted against up-link e.i.r.p. in Fig. 1 and Fig. 2 respectively. The apparent spread in the measured results can be attributed to the accuracy and resolution of the measuring instruments and several other factors; variation in the satellite sensitivity (G/T) and e.i.r.p. due to movement of the satellite platform throughout the day with consequent antenna de-pointing, and changes in the transponder gain due to temperature variation (the transponder does not incorporate a.g.c.). The spread was certainly no larger than would be expected.

Fortunately, during the tests the weather conditions on both the up- and down-links were good (clear to cloudy, but no rain), so the test results represent typical values for some 99% of time. If poor weather conditions had prevailed the results would need careful interpretation because radiometers were not available at the earth station sites to allow measurement of the sky noise-temperature, and hence estimation of the precipitation loss.

The results of the subjective tests show that the f.m. demodulator at Madley approached threshold conditions at a C/N of about 12 dB, and was definitely producing threshold noise spikes at 11 dB, regardless of the i.f. bandwidth in use, as would be expected. Furthermore, the 0.8 dB difference between the two i.f. bandwidths was borne out by the apparent 1 dB depression of the threshold in the results of the subjective tests when "half transponder" conditions were used.

It follows that with the e.i.r.p. limitation of 72 dBW, a high-quality vision circuit can be provided to London with the TES located anywhere within

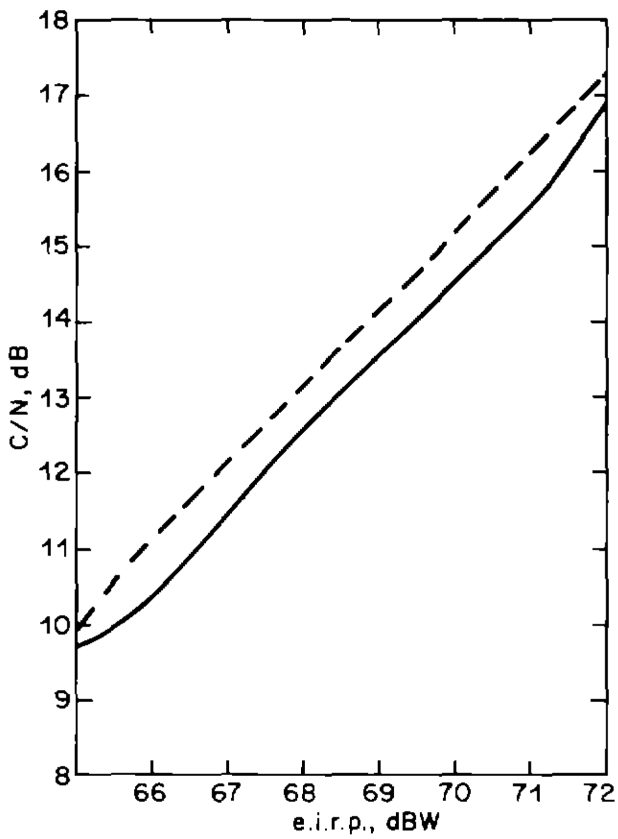

*Fig. 1 — Measured received C/N ratio vs. TES transmitted e.i.r.p.**

——— "standard" operating conditions

– – – – "half transponder" conditions

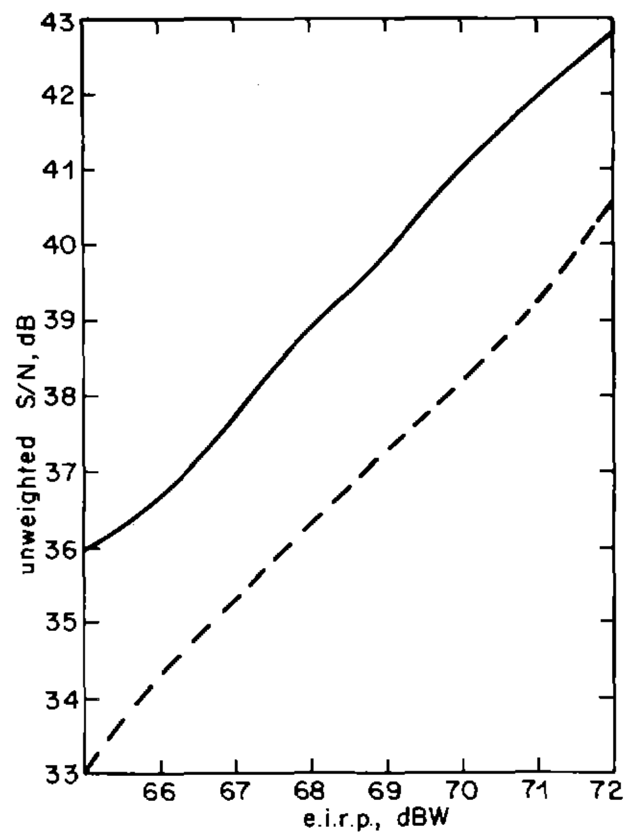

*Fig. 2 — Measured received S/N ratio vs. TES transmitted e.i.r.p.**

——— "standard" operating conditions

– – – – "half transponder" conditions

the −1.5 dB contour of the ECS Eurobeam**, and under these conditions the fading margin will be about 4 dB. This will allow operation for all but 0.02% of time (1.75 hours per year). If a slightly degraded S/N is accepted then the margin will be increased by 1 dB by adopting "half transponder" conditions.

Of course, fading margin can be traded for coverage as, for instance, operation at the −3 dB contour would yield some 2.5 dB margin with "standard" operating conditions, and this would allow operation for all but 0.06% of time (5.25 hours per year). The −1.5 dB and −3 dB Eurobeam contours are illustrated in Fig. 3; the −3 dB contour covers all of the UK, most of Europe and part of North Africa.

* Via ECS 2, transponder 9, with clear weather conditions and a receiving earth station G/T of 41.6 dB.

** The EBU-leased transponders on ECS 2 are normally connected to Eurobeam antennas for both up- and down-links. Spot beams, when available in the ECS system, are only used for down-links.

The TES is equipped with a receiving system[1] which has been used for loop tests and to monitor the signal output by the satellite. This was most useful when links were conducted via the OTS, using the full TES transmitter power and a transponder connected to a Spotbeam down-link antenna.

Operation with the Eurobeam down-link of the ECS with reduced TES transmitter power will not yield above-threshold signals when using this on-board receiver. There is a facility for reducing the noise-bandwidth of the receiver to increase the received C/N, but this introduces severe non-linearity when the f.m. spectrum is truncated. Therefore the monitoring ability of the TES is all but removed under these conditions. However, in 1981 when the TES was first used the need for on-board monitoring was much greater than nowadays, when operation with transportable earth stations is a more-commonplace requirement for large (receiving) earth station operators.

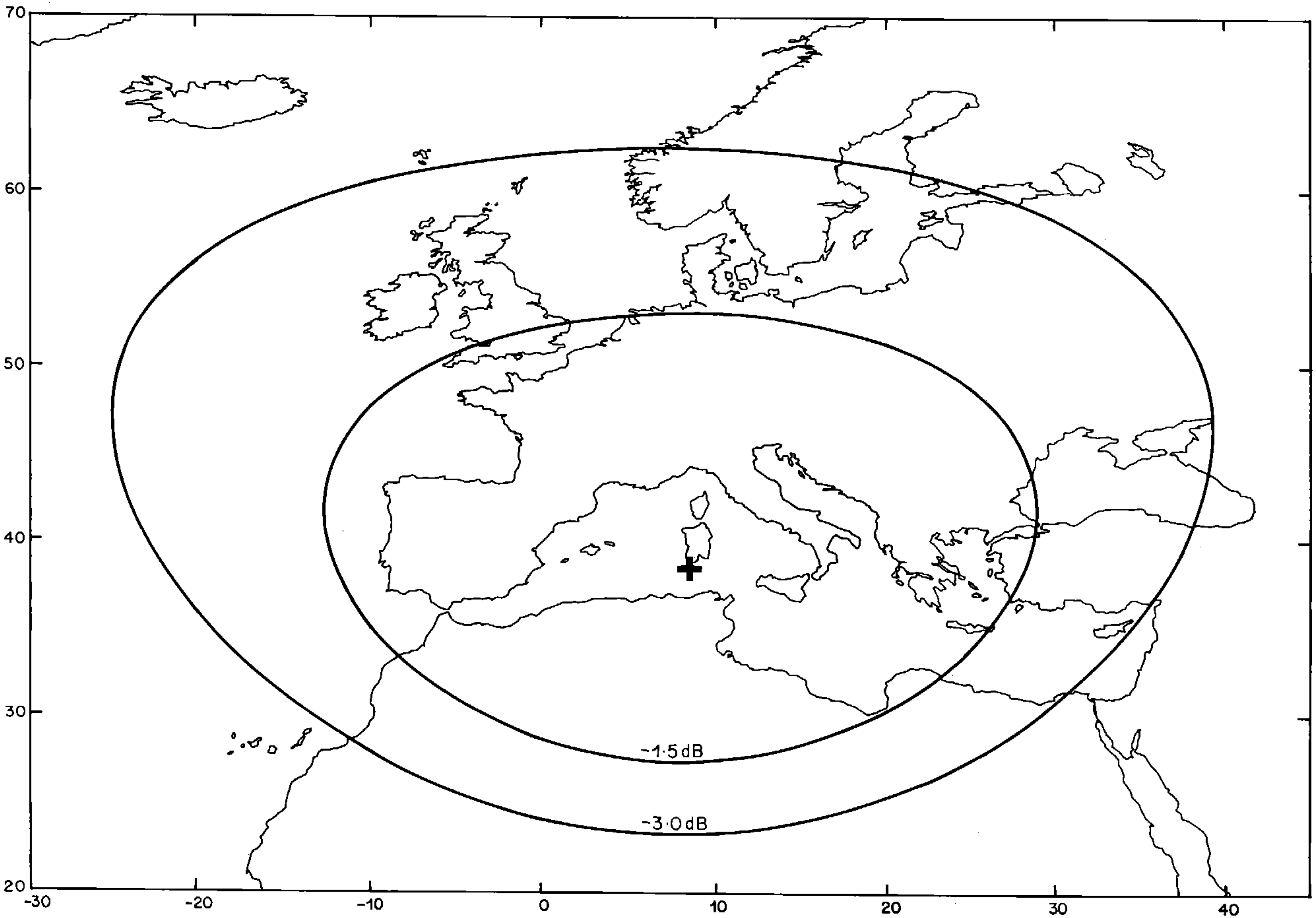

Fig. 3 — ECS Eurobeam coverage.

✚ marks the beam centre (0dB) aim point.

The TES receiving system will be of continued value for locating satellites by receiving beacon signals and for conducting loop tests on the transmitting equipment.

6. Conclusions

It can be concluded that, with the present values of the satellite and receiving earth station characteristics, the 72 dBW e.i.r.p. restriction is no obstacle to the continued use of the Transportable Earth Station for outside broadcast coverage of events in Europe.

For much of Europe within the −1.5 dB satellite beam contour the fading margin of 4 dB will be adequate for all but 0.02% of time (1.75 hours per year). For more Northerly regions of the UK and the rest of Europe, within the −3 dB contour of the ECS Eurobeam, the 2.5 dB fading margin will be adequate for all but 5.25 hours per year. With the possibility of gaining an extra 1 dB of fading margin by adopting "half transponder" conditions, operation out to the −3 dB contour should not be significantly curtailed. Additionally, there may be possiblities for increasing the coverage area still further if a lower S/N ratio can be accepted (e.g. for new gathering), using even smaller values of f.m. deviation and receiver bandwidth.

Throughout the life of the satellite the satellite characteristic which is most likely to be degraded is the e.i.r.p. rather than the G/T. With some 6 dB difference between the up- and down-link C/N ratios this will have a relatively minor impact on the overall link C/N.

It is important to note that the results described apply to the use of a large receiving earth station with a 17m diameter antenna and a G/T in excess of 41 dBK^{-1}. The monitoring receiver built into the TES uses the 3m diameter antenna and has a G/T of 22 dBK^{-1} so its usefulness is severely limited under these conditions.

No anomalous behaviour was noticed in the operation of the transponder, and it can be inferred that a.m./p.m. conversion is at a low level (certainly much less than the 6°/dB maximum specification) when the transponder is operated with the TES as described in the Report.

7. Acknowledgement

The assistance of staff from BTI, IBA, ITN and BBC Designs, Communications and Television Outside Broadcasts Departments is gratefully acknowledged, for the provision of equipment and facilities, and for useful discussions.

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9. Appendix

Link budget

The characteristics of elements in the satellite link can be compiled in the form of a link power budget. The following case considers an up-link e.i.r.p. of 72 dBW and "standard" operating conditions:

Up-link :	Transmit e.i.r.p. from TES at Acton	72.0 dBW
	– Path loss and atmospheric loss	–207.7 dB
	– Eurobeam relative gain towards Acton	–1.5 dB
	+ Satellite beam-centre G/T	+1.7 dBK^{-1}
	– Boltzman constant	+228.6 $dBWHz^{-1}\ K^{-1}$
	– Effective noise bandwidth	–75.6 dBHz
	= Effective up-link C/N	17.5 dB
Satellite :	Beam-centre i.p.f.d. for saturation	–80.2 $dBWm^{-2}$
	– Actual i.p.f.d.	–92.6 $dBWm^{-2}$
	= Input backoff	12.4 dB
	∴ Output backoff	5.5 dB*
Down-link:	Beam-centre saturated e.i.r.p.	41.6 dBW
	– Output backoff	–5.5 dB
	– Eurobeam relative gain towards Madley	–1.5 dB
	– Path loss and atmospheric loss	–205.3 dB
	+ Madley clear-weather G/T	+41.6 dBK^{-1}
	– Boltzman constant	+228.6 $dBWHz^{-1}\ K^{-1}$
	– Receiver noise bandwidth	–75.6 dBHz
	= Down-link C/N	23.9 dB
	∴ Overall link C/N	16.6 dB
	Mean measured C/N	16.8 dB

The satellite beam-centre G/T is specified by Interim Eutelsat within a tolerance of ± 0.5 dB per day and this will effect the overall link C/N. The spread of measured C/N values, over the day, was ± 0.4 dB.

* This value was obtained from TWT data supplied by BTI.

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